A Framework for Flexible And Secure Access to Space

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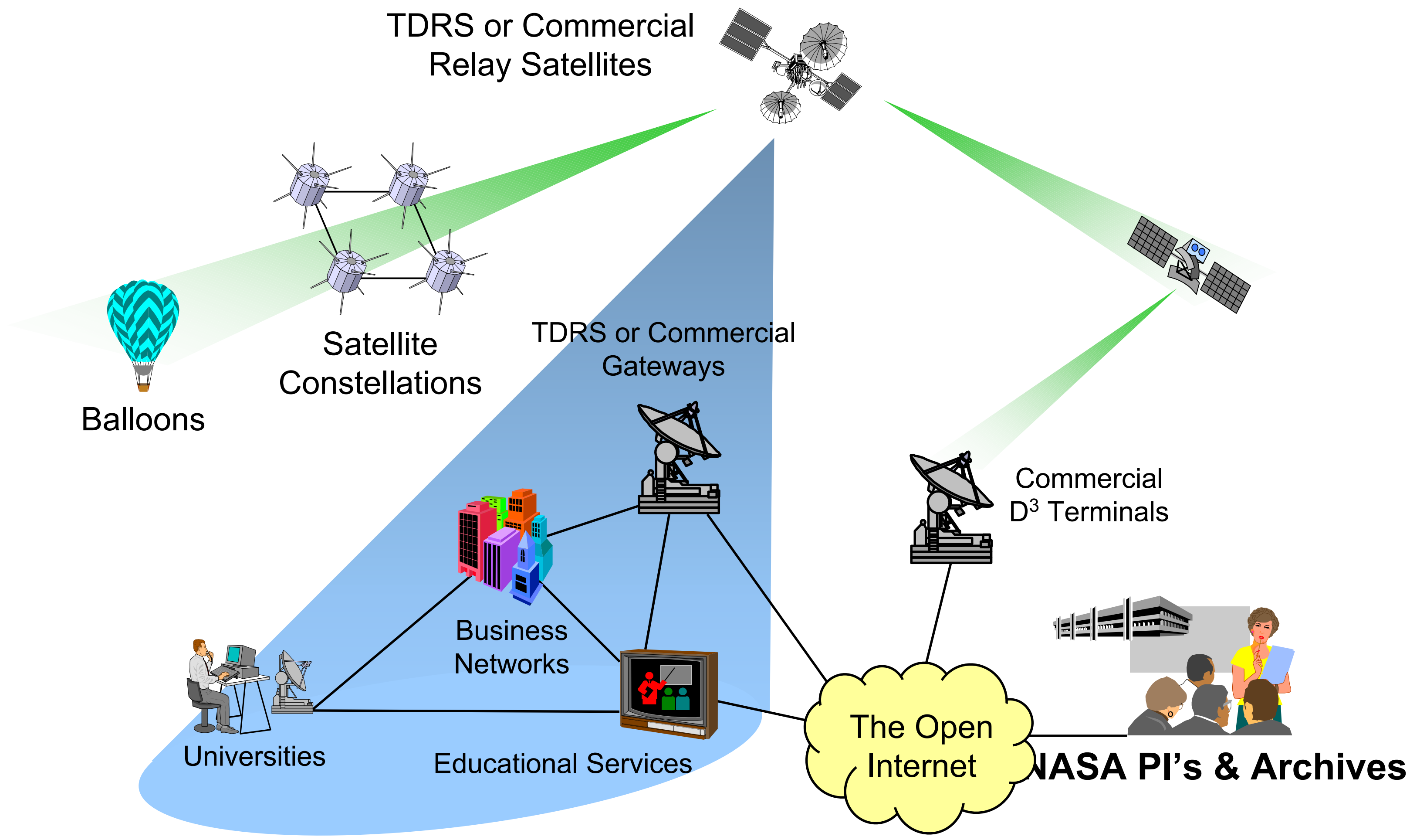
Goals & Objectives

- Develop a quantitative, mathematical and statistical basis for analyzing changes to NASA communications network architectures in order to enable NASA's vision of an adaptive, intelligent communications architecture.
- Investigate network optimization, software and communication issues for missions in order to maximize science return and enable the transition to an IP-based, dynamic mission operation.
- Investigate inter-operable solutions that can result in enhanced service and reduced cost by integrating components & technology from other infrastructures (DoD, other Space Agencies, Commercial Systems where possible).

Future Mission Network Evolution

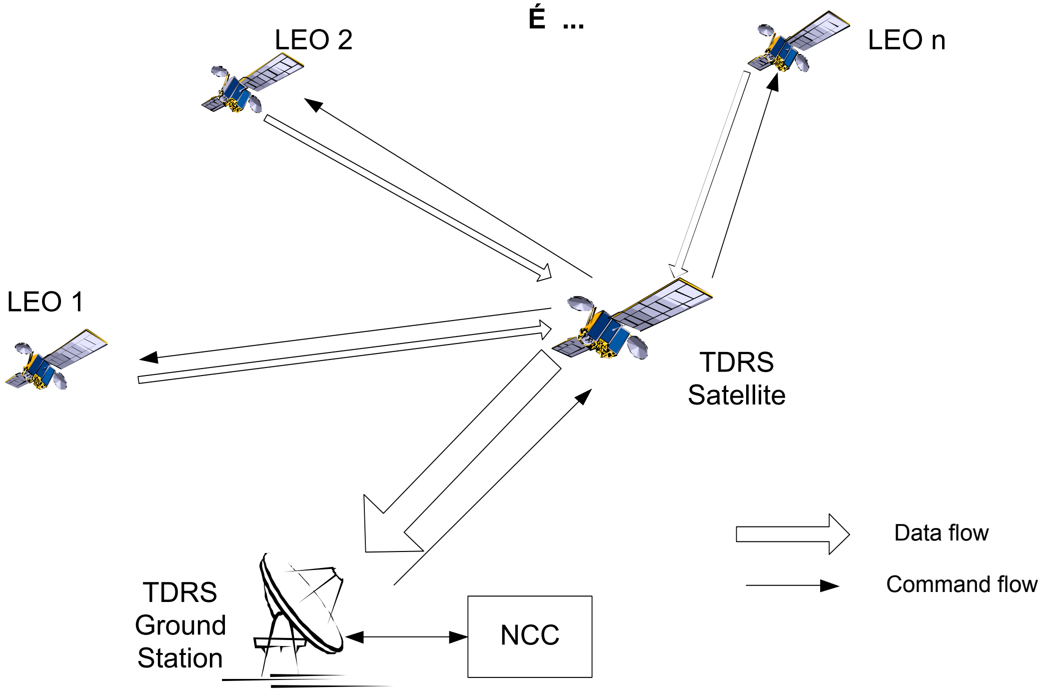


Infrastructure Requirements for Future IP-Based NASA Network

- **Support Interactivity with Users**
- **Allow Dynamic Operations**
- **Support Flexible Resource allocation**
  - Demand access for Capacity
  - Shared Resources in Space and on Ground
- **Dynamic, Robust and Energy Efficient Routing**
- **Re-configurable Network with Modular Component Re-usability**
- **Gradual Upgrades possible as demand increases**
- **Support of Intermittent Connectivity**
- **Support autonomous operation if necessary**
- **End-to-End Security**
- **Commercial technology, non-NASA assets in space and on the ground and standard communication protocols can be employed (where possible).**
- **Still able to support Legacy (non-IP) spacecraft**

Problem Definition

- Transition to dynamic mission operations will require the ability to adapt to changing traffic loads, accommodate various priorities on different spacecraft and offer flexible and secure access to addressable spacecraft.

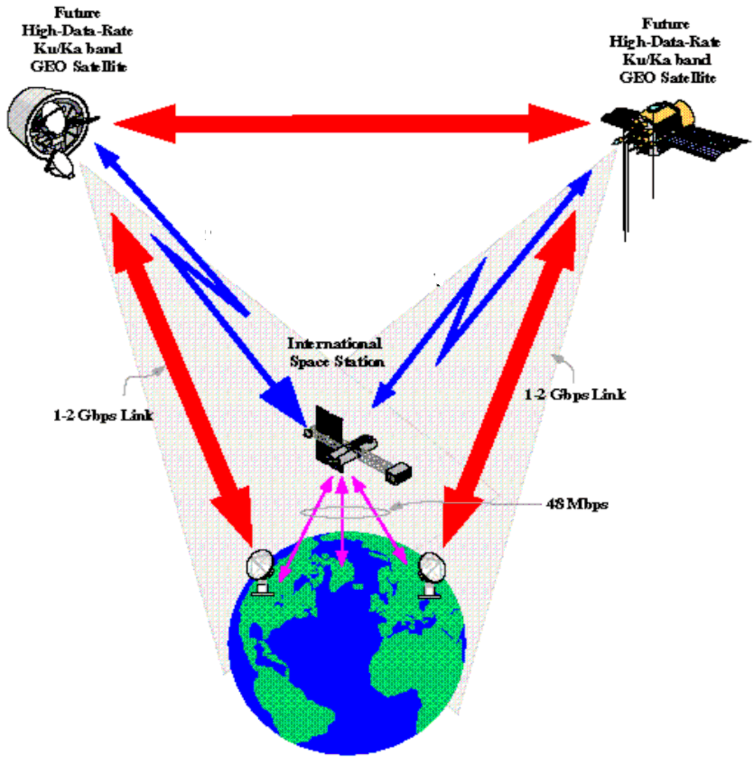


Requirements for Dynamic Mission Operations

To enable an on-demand operation that efficiently supports multiple spacecraft we need to:

- **Study candidate architectures & topologies**
- **Understand Mission Traffic Characteristics, priorities and QoS guarantees that must be met**
- **Develop an on-demand mode multiple access able to support space to ground communications**
- **Implement suitable layered protocol support and security solution.**

Scenarios for Improved Data Delivery



- **Data Relay to Ground via :**
  - NASA TDRS
  - Other Relay Options (DoD, Commercial)
- **Direct-to-Ground Transmission**
  - NASA Ground Network facilities
  - Other (smaller & distributed) Ground Terminals (e.g. Universal Space Network) or Direct-to-User solutions

Improved Data Delivery

- Define alternative communication architectures missions can use (based on existing assets on the ground and in space)
- Study the trade-off between sending data to one NASA ground station vs. several geographically distributed ground terminals
- Access to ground stations: Determine how frequently and for how long need to access ground station for reliable delivery of information. Study trade-off in reduction in receiving dish size achieved by downloading data more frequently.

Understanding NASA Mission Traffic

- **Establish a baseline set of statistical models of the traffic currently carried on NASA networks, driven by usage statistics collected by NASA relay sites (Rely on NASA to provide the relevant information).**
- **Extrapolate models for addressing future NASA communications traffic,**
- **Employ models representing current and planned communications traffic to analyze candidate architectures wrt:**
  - Access
  - Total throughput & Delay
  - Quality of Service support for different priorities

Developing Dynamic Access Solutions

As number of users (spacecraft) and associated data volumes increase, need an efficient MAC scheme that satisfies the following requirements:

- **Multiple Spacecraft share access to ground station efficiently**
- **Provides required QoS guarantees for different classes, priorities of traffic (TT&C, science data)**
- **Handles mobility of spacecraft**
- **Takes advantage of special architecture (limited number of users, predictable mobility)**

Dynamic Access

- Define a conceptual architecture and evaluate criteria for suitable multiple access techniques
- Build on existing simulation model and develop a flexible platform that can model detailed spacecraft mobility and network performance for different topologies.
- Employ background in optimizing multiple access for satellite systems in addressing the Multiple Access/Dynamic Capacity allocation problem in the simulated environment.

Security Issues in IP Space Network

- **IF IP access is introduced and NASA spacenet is connected to other heterogeneous components potential risk and mitigation strategies must be addressed:**
  - Encryption Impact on CPU Utilization
  - Throughput Degradation
  - Added Delays
  - Added Overhead
  - Interoperability Issues
- **NASA GSFC Code 297 (Enterprise IT security Branch) has been studying IP-in-Space issues and developing a prototype "IP-in-Space Security Handbook".**

Security Issues

- **Dealing with TCP inefficiencies over space links using PEP will not work in the IPSEC environment. Since the co-location of the IPSEC and PEP is not guaranteed, the proliferation of an enhanced TCP protocol that works efficiently for high values of bit rate and delay product would be required. We are investigating protocol enhancements essential for efficient operation over space links, with criteria:**
  - (a) TCP with the enhancements should be backward compatible with the current TCP implementation,
  - (b) The complexity of implementing the enhanced TCP should be minimum.
  - (c) It might be desirable if such enhancement is a subset of an IETF RFC.
- **We are also investigating solutions such as L-IPSEC or other approaches that can work well in the space environment.**
- **Need to examine the impact on proposed procedures solution on level of security Vs. reduction in performance and mission system complexity and cost.**

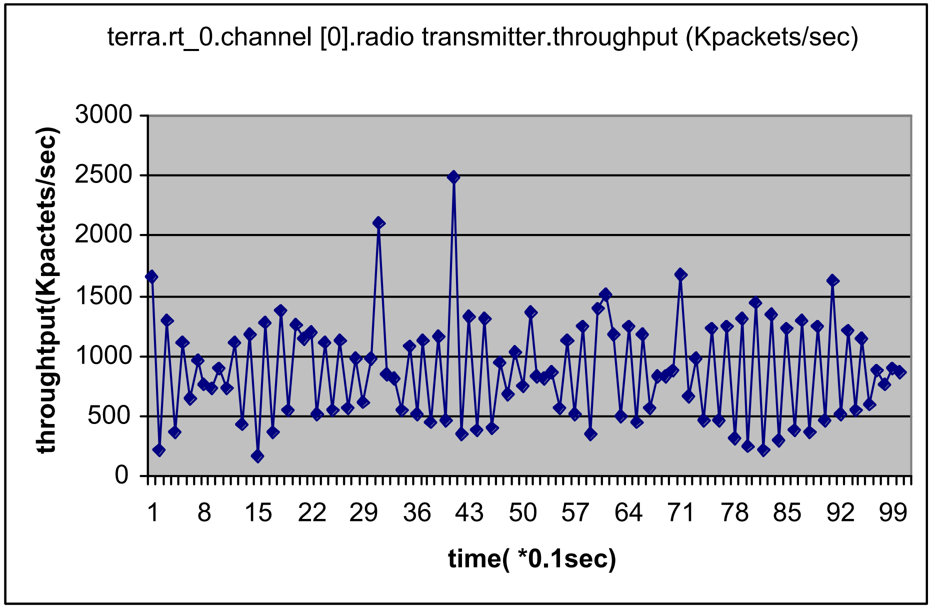
Modeling Tool Development

- Developing a discrete event modular simulation platform based on OPNET that includes:
  - The NASA DSN Network
  - The NASA TDRS Relay Network
  - Other potential relays using commercial satellite constellations
  - Other potential Direct-to-Ground Relays
  - The International Space Station
  - Models of typical mission spacecraft (such as MMS and TERRA) and detailed orbital models using the Satellite Tool Kit (STK) or importing from NASA modeling test-beds for the above spacecraft.
- The model includes network elements such as traffic generation, layered protocol support, MAC layer and physical channel and antenna properties.
- Objective would be to integrate parts of the model with related test-beds under development at NASA GRC and NASA GSFC or other potential facilities.

Traffic Modeling for Science Missions

Examples of typical mission traffic models:

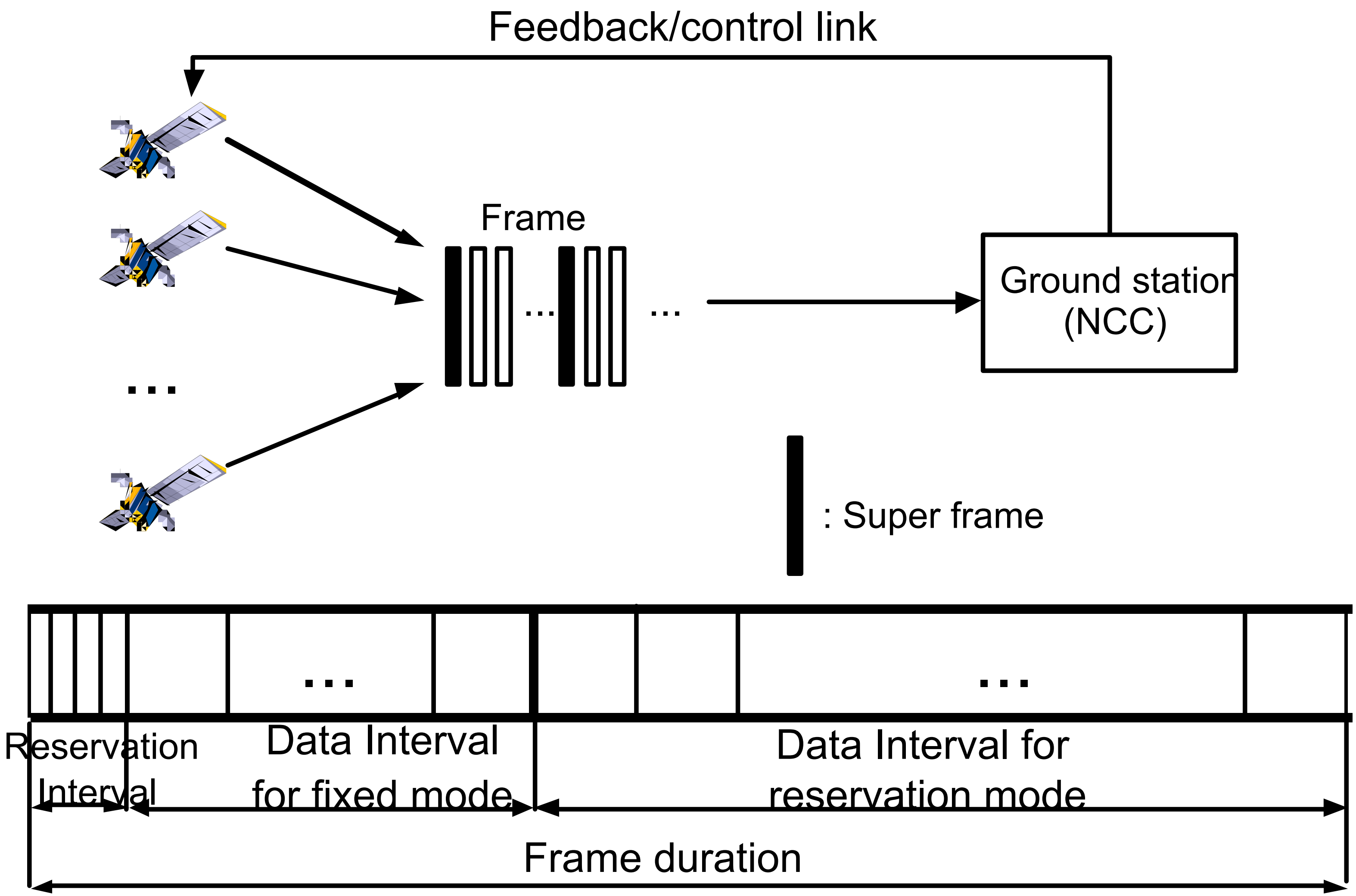
- Defined a sample mission scenario, using the ESE TERRA mission, determined the details of the data generation of the instruments and packetization and queuing on-board.
- Developed a model of traffic for MMS mission based on activity of magnetosphere data



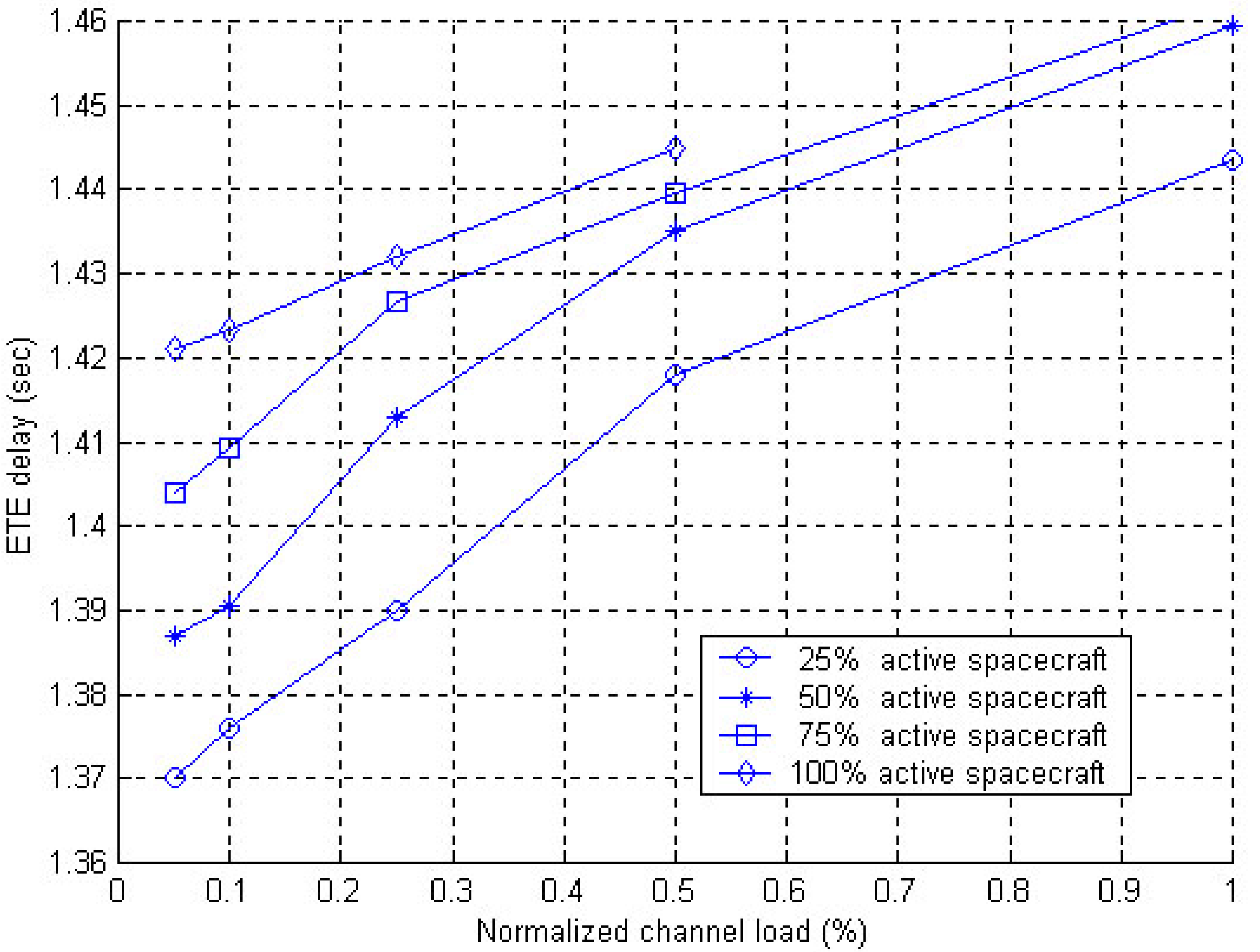
Dynamic Access
Proposed RD-TDMA Scheme

- Although a lot of demand TDMA protocols were proposed in the literature, they addressed the MAC issues for cellular network and packet-switched radio satellite network architecture.
- Proposed RD-TDMA protocol for our unique LEO network scenario with the novel on-demand mode network architecture.
  - **The RD-TDMA protocol is a reservation based demand TDMA protocol.**
  - **It uses slotted-ALOHA for reservation(other CRAs will be considered).**
- Advantages of Proposed RD-TDMA
  - **efficient in bandwidth utilization under bursty traffic;**
  - **able to accommodate larger number of spacecrafts.**
- Note: TDMA approach is a practical starting point, considering other solutions (e.g. CDMA/WDM) is possible later on

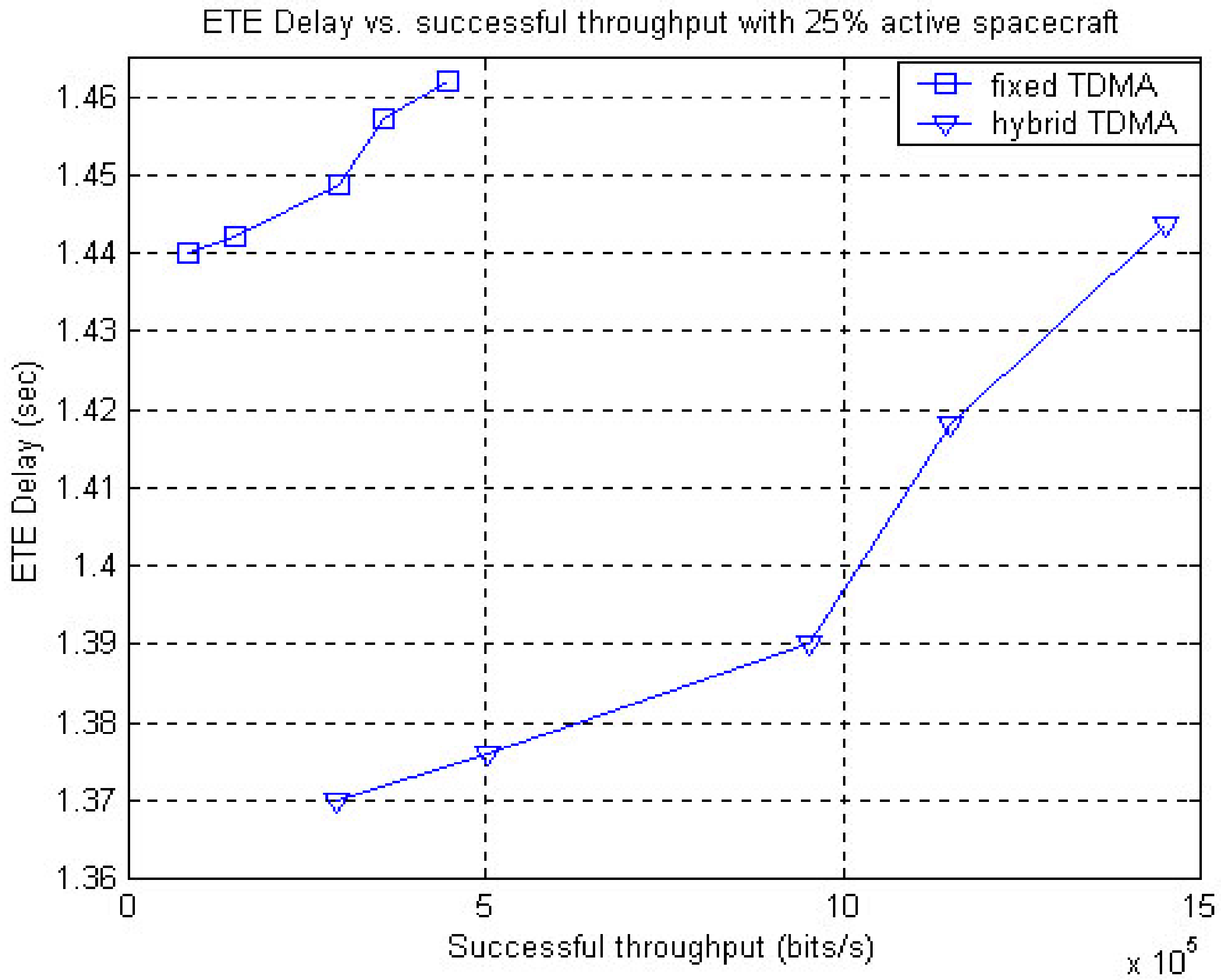
On-Demand MAC for Dynamic Mission Operations- Protocol Operation



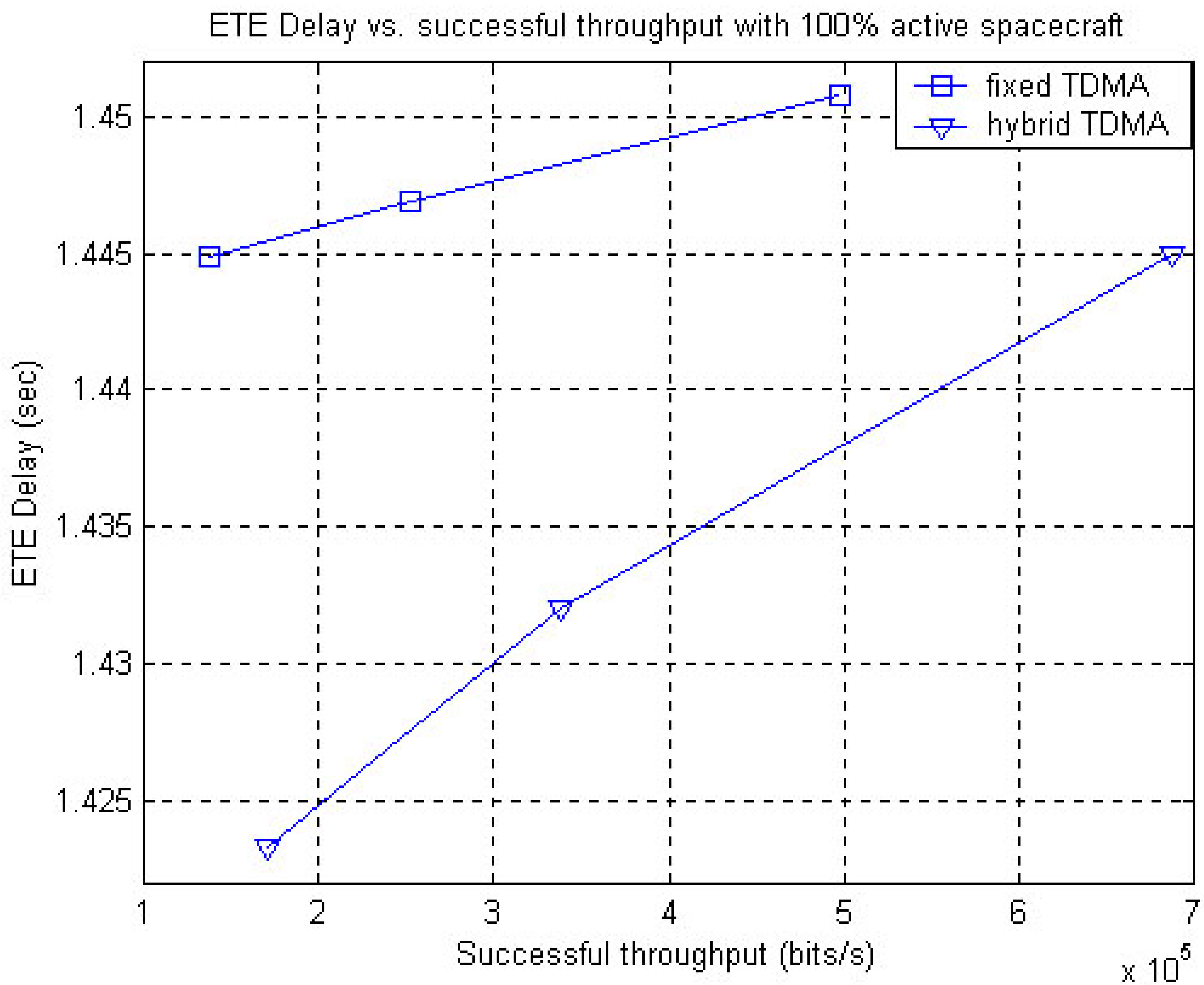
On-Demand MAC for Dynamic Mission Operations-Performance Comparison (TDRS Relay Case)



Dynamic Access Results (2)



Dynamic Access Results (3)



Summary

- Defined the need for understanding mission traffic characteristics, and dynamically sharing access to Ground Stations by mission spacecraft, with priorities and QoS guarantees.
- Addressed multiple access for this topology and proposed a basis for developing a suitable Demand MAC Protocol
- Developed a modular simulation test-bed that includes satellite orbits/mobility, coverage, traffic and network modules.
- Performed initial simulation study with a set-up of EOS typical Missions, started analysing traffic, coverage, access optimization aspects.
- Started investigation security & performance issues related to IP-based space networks
- Initial simulation results prove that for sample scenario on-demand mode has significant advantages over pre-planned mode, especially under bursty traffic load condition leading to :
  - **More efficient utilization of bandwidth,**
  - **Accommodating larger network(space user) size**
  - **Different or even Hybrid topologies can be used for various types of service support, provided carefull assessment of QoS requirements is performed.**

Future Work

What we plan to do next:

- Formulate and optimize a dynamic multi-access protocol that offers both guaranteed and on-demand sharing of the available bandwidth
- Perform end-to-end optimization and suggest solutions that would support particular protocols or QoS requirements for specific services over the space-to-ground link that might involve:
  - i. special random access slot can be added to the TDMA frame, which is used for short file transmission without reservation.
  - ii. Adaptive collision algorithms can be developed to minimize the number of contentions.
  - iii. a priority-based solution
- Investigate traffic statistics (provided by NASA) to determine how we can adapt protocol operation to reflect realistic traffic scenarios
- Implement a discrete event simulation of this with several spacecraft in orbit generating appropriate traffic
- Address potential problems with PEP-based solutions to TCP introduced if IPSec is used, and investigate alternative security approaches.